US009343086B1

(12) **United States Patent**
Liu et al.

(10) **Patent No.: US 9,343,086 B1**
(45) **Date of Patent: May 17, 2016**

(54) **MAGNETIC RECORDING WRITE TRANSDUCER HAVING AN IMPROVED SIDEWALL ANGLE PROFILE**

(71) Applicant: **Western Digital (Fremont), LLC**, Fremont, CA (US)

(72) Inventors: **Feng Liu**, San Ramon, CA (US); **Zhigang Bai**, Fremont, CA (US); **Yugang Wang**, Milpitas, CA (US); **Tao Pan**, San Jose, CA (US)

(73) Assignee: **Western Digital (Fremont), LLC**, Fremont, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/051,359**

(22) Filed: **Oct. 10, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/876,340, filed on Sep. 11, 2013.

(51) **Int. Cl.**
G11B 5/147 (2006.01)
G11B 5/127 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/1278*** (2013.01)

(58) **Field of Classification Search**
CPC G11B 5/3116; G11B 5/1278
USPC 360/125.08–125.15
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,801,910	A	9/1998	Mallary
6,016,290	A	1/2000	Chen et al.
6,018,441	A	1/2000	Wu et al.
6,025,978	A	2/2000	Hoshi et al.
6,025,988	A	2/2000	Yan
6,032,353	A	3/2000	Hiner et al.
6,033,532	A	3/2000	Minami
6,034,851	A	3/2000	Zarouri et al.
6,043,959	A	3/2000	Crue et al.
6,046,885	A	4/2000	Aimonetti et al.
6,049,650	A	4/2000	Jerman et al.
6,055,138	A	4/2000	Shi
6,058,094	A	5/2000	Davis et al.
6,073,338	A	6/2000	Liu et al.
6,078,479	A	6/2000	Nepela et al.
6,081,499	A	6/2000	Berger et al.
6,094,803	A	8/2000	Carlson et al.
6,099,362	A	8/2000	Viches et al.
6,103,073	A	8/2000	Thayamballi
6,108,166	A	8/2000	Lederman
6,118,629	A	9/2000	Huai et al.
6,118,638	A	9/2000	Knapp et al.
6,125,018	A	9/2000	Takagishi et al.

(Continued)

OTHER PUBLICATIONS

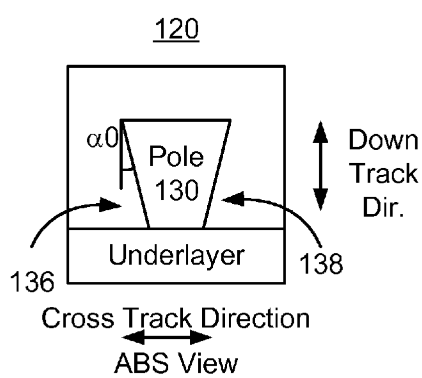
U.S. Appl. No. 13/631,808, filed Sep. 28, 2012, to Liu et al., 16 pages.

Primary Examiner — Gustavo Polo

(57) **ABSTRACT**

A method and system provide a magnetic transducer having an air-bearing surface (ABS). The magnetic transducer includes a main pole and at least one coil for energizing the main pole. The main pole includes a pole tip region and a yoke region. The pole tip region includes sidewalls, a bottom and a top wider than the bottom. At least one of the sidewalls forms a first sidewall angle with a down track direction at the ABS and a second sidewall angle with the down track direction at a first distance recessed from the ABS. The first sidewall angle is greater than the second sidewall angle.

28 Claims, 6 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,130,779	A	10/2000	Carlson et al.
6,134,089	A	10/2000	Barr et al.
6,136,166	A	10/2000	Shen et al.
6,137,661	A	10/2000	Shi et al.
6,137,662	A	10/2000	Huai et al.
6,160,684	A	12/2000	Heist et al.
6,163,426	A	12/2000	Nepela et al.
6,166,891	A	12/2000	Lederman et al.
6,172,848	B1	1/2001	Santini
6,173,486	B1	1/2001	Hsiao et al.
6,175,476	B1	1/2001	Huai et al.
6,178,066	B1	1/2001	Barr
6,178,070	B1	1/2001	Hong et al.
6,178,150	B1	1/2001	Davis
6,181,485	B1	1/2001	He
6,181,525	B1	1/2001	Carlson
6,185,051	B1	2/2001	Chen et al.
6,185,077	B1	2/2001	Tong et al.
6,185,081	B1	2/2001	Simion et al.
6,188,549	B1	2/2001	Wiitala
6,190,764	B1	2/2001	Shi et al.
6,193,584	B1	2/2001	Rudy et al.
6,195,229	B1	2/2001	Shen et al.
6,198,608	B1	3/2001	Hong et al.
6,198,609	B1	3/2001	Barr et al.
6,201,673	B1	3/2001	Rottmayer et al.
6,204,998	B1	3/2001	Katz
6,204,999	B1	3/2001	Crue et al.
6,212,153	B1	4/2001	Chen et al.
6,215,625	B1	4/2001	Carlson
6,219,205	B1	4/2001	Yuan et al.
6,221,218	B1	4/2001	Shi et al.
6,222,707	B1	4/2001	Huai et al.
6,229,782	B1	5/2001	Wang et al.
6,230,959	B1	5/2001	Heist et al.
6,233,116	B1	5/2001	Chen et al.
6,233,125	B1	5/2001	Knapp et al.
6,237,215	B1	5/2001	Hunsaker et al.
6,252,743	B1	6/2001	Bozorgi
6,255,721	B1	7/2001	Roberts
6,258,468	B1	7/2001	Mahvan et al.
6,266,216	B1	7/2001	Hikami et al.
6,271,604	B1	8/2001	Frank, Jr. et al.
6,275,354	B1	8/2001	Huai et al.
6,277,505	B1	8/2001	Shi et al.
6,282,056	B1	8/2001	Feng et al.
6,296,955	B1	10/2001	Hossain et al.
6,297,955	B1	10/2001	Frank, Jr. et al.
6,304,414	B1	10/2001	Crue, Jr. et al.
6,307,715	B1	10/2001	Berding et al.
6,310,746	B1	10/2001	Hawwa et al.
6,310,750	B1	10/2001	Hawwa et al.
6,317,290	B1	11/2001	Wang et al.
6,317,297	B1	11/2001	Tong et al.
6,322,911	B1	11/2001	Fukagawa et al.
6,330,136	B1	12/2001	Wang et al.
6,330,137	B1	12/2001	Knapp et al.
6,333,830	B2	12/2001	Rose et al.
6,340,533	B1	1/2002	Ueno et al.
6,349,014	B1	2/2002	Crue, Jr. et al.
6,351,355	B1	2/2002	Min et al.
6,353,318	B1	3/2002	Sin et al.
6,353,511	B1	3/2002	Shi et al.
6,356,412	B1	3/2002	Levi et al.
6,359,779	B1	3/2002	Frank, Jr. et al.
6,369,983	B1	4/2002	Hong
6,376,964	B1	4/2002	Young et al.
6,377,535	B1	4/2002	Chen et al.
6,381,095	B1	4/2002	Sin et al.
6,381,105	B1	4/2002	Huai et al.
6,389,499	B1	5/2002	Frank, Jr. et al.
6,392,850	B1	5/2002	Tong et al.
6,396,660	B1	5/2002	Jensen et al.
6,399,179	B1	6/2002	Hanrahan et al.
6,400,526	B2	6/2002	Crue, Jr. et al.
6,404,600	B1	6/2002	Hawwa et al.
6,404,601	B1	6/2002	Rottmayer et al.
6,404,706	B1	6/2002	Stovall et al.
6,410,170	B1	6/2002	Chen et al.
6,411,522	B1	6/2002	Frank, Jr. et al.
6,417,998	B1	7/2002	Crue, Jr. et al.
6,417,999	B1	7/2002	Knapp et al.
6,418,000	B1	7/2002	Gibbons et al.
6,418,048	B1	7/2002	Sin et al.
6,421,211	B1	7/2002	Hawwa et al.
6,421,212	B1	7/2002	Gibbons et al.
6,424,505	B1	7/2002	Lam et al.
6,424,507	B1	7/2002	Lederman et al.
6,430,009	B1	8/2002	Komaki et al.
6,430,806	B1	8/2002	Chen et al.
6,433,965	B1	8/2002	Gopinathan et al.
6,433,968	B1	8/2002	Shi et al.
6,433,970	B1	8/2002	Knapp et al.
6,437,945	B1	8/2002	Hawwa et al.
6,445,536	B1	9/2002	Rudy et al.
6,445,542	B1	9/2002	Levi et al.
6,445,553	B2	9/2002	Barr et al.
6,445,554	B1	9/2002	Dong et al.
6,447,935	B1	9/2002	Zhang et al.
6,448,765	B1	9/2002	Chen et al.
6,451,514	B1	9/2002	Iitsuka
6,452,742	B1	9/2002	Crue et al.
6,452,765	B1	9/2002	Mahvan et al.
6,456,465	B1	9/2002	Louis et al.
6,459,552	B1	10/2002	Liu et al.
6,462,920	B1	10/2002	Karimi
6,466,401	B1	10/2002	Hong et al.
6,466,402	B1	10/2002	Crue, Jr. et al.
6,466,404	B1	10/2002	Crue, Jr. et al.
6,468,436	B1	10/2002	Shi et al.
6,469,877	B1	10/2002	Knapp et al.
6,477,019	B2	11/2002	Matono et al.
6,479,096	B1	11/2002	Shi et al.
6,483,662	B1	11/2002	Thomas et al.
6,487,040	B1	11/2002	Hsiao et al.
6,487,056	B1	11/2002	Gibbons et al.
6,490,125	B1	12/2002	Barr
6,496,330	B1	12/2002	Crue, Jr. et al.
6,496,334	B1	12/2002	Pang et al.
6,504,675	B1	1/2003	Shukh et al.
6,504,676	B1	1/2003	Hiner et al.
6,512,657	B2	1/2003	Heist et al.
6,512,659	B1	1/2003	Hawwa et al.
6,512,661	B1	1/2003	Louis
6,512,690	B1	1/2003	Qi et al.
6,515,573	B1	2/2003	Dong et al.
6,515,791	B1	2/2003	Hawwa et al.
6,532,823	B1	3/2003	Knapp et al.
6,535,363	B1	3/2003	Hosomi et al.
6,552,874	B1	4/2003	Chen et al.
6,552,928	B1	4/2003	Qi et al.
6,577,470	B1	6/2003	Rumpler
6,583,961	B2	6/2003	Levi et al.
6,583,968	B1	6/2003	Scura et al.
6,597,548	B1	7/2003	Yamanaka et al.
6,611,398	B1	8/2003	Rumpler et al.
6,618,223	B1	9/2003	Chen et al.
6,629,357	B1	10/2003	Akoh
6,633,464	B2	10/2003	Lai et al.
6,636,394	B1	10/2003	Fukagawa et al.
6,639,291	B1	10/2003	Sin et al.
6,650,503	B1	11/2003	Chen et al.
6,650,506	B1	11/2003	Risse
6,654,195	B1	11/2003	Frank, Jr. et al.
6,657,816	B1	12/2003	Barr et al.
6,661,621	B1	12/2003	Iitsuka
6,661,625	B1	12/2003	Sin et al.
6,674,610	B1	1/2004	Thomas et al.
6,680,863	B1	1/2004	Shi et al.
6,683,763	B1	1/2004	Hiner et al.
6,687,098	B1	2/2004	Huai
6,687,178	B1	2/2004	Qi et al.
6,687,977	B2	2/2004	Knapp et al.
6,691,226	B1	2/2004	Frank, Jr. et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,697,294	B1	2/2004	Qi et al.
6,700,738	B1	3/2004	Sin et al.
6,700,759	B1	3/2004	Knapp et al.
6,704,158	B2	3/2004	Hawwa et al.
6,707,083	B1	3/2004	Hiner et al.
6,710,973	B2	3/2004	Okada et al.
6,713,801	B1	3/2004	Sin et al.
6,721,138	B1	4/2004	Chen et al.
6,721,149	B1	4/2004	Shi et al.
6,721,203	B1	4/2004	Qi et al.
6,722,018	B2	4/2004	Santini
6,724,569	B1	4/2004	Chen et al.
6,724,572	B1	4/2004	Stoev et al.
6,729,015	B2	5/2004	Matono et al.
6,731,460	B2	5/2004	Sasaki
6,735,850	B1	5/2004	Gibbons et al.
6,737,281	B1	5/2004	Dang et al.
6,738,223	B2	5/2004	Sato et al.
6,744,608	B1	6/2004	Sin et al.
6,747,301	B1	6/2004	Hiner et al.
6,751,055	B1	6/2004	Alfoqaha et al.
6,754,049	B1	6/2004	Seagle et al.
6,756,071	B1	6/2004	Shi et al.
6,757,140	B1	6/2004	Hawwa
6,760,196	B1	7/2004	Niu et al.
6,762,910	B1	7/2004	Knapp et al.
6,762,911	B2	7/2004	Sasaki et al.
6,765,756	B1	7/2004	Hong et al.
6,775,902	B1	8/2004	Huai et al.
6,778,358	B1	8/2004	Jiang et al.
6,781,927	B1	8/2004	Heanuc et al.
6,785,955	B1	9/2004	Chen et al.
6,791,793	B1	9/2004	Chen et al.
6,791,807	B1	9/2004	Hikami et al.
6,798,616	B1	9/2004	Seagle et al.
6,798,625	B1	9/2004	Ueno et al.
6,801,408	B1	10/2004	Chen et al.
6,801,411	B1	10/2004	Lederman et al.
6,803,615	B1	10/2004	Sin et al.
6,806,035	B1	10/2004	Atireklapvarodom et al.
6,807,030	B1	10/2004	Hawwa et al.
6,807,332	B1	10/2004	Hawwa
6,809,899	B1	10/2004	Chen et al.
6,813,116	B2	11/2004	Nakamura et al.
6,816,345	B1	11/2004	Knapp et al.
6,828,897	B1	12/2004	Nepela
6,829,160	B1	12/2004	Qi et al.
6,829,819	B1	12/2004	Crue, Jr. et al.
6,833,979	B1	12/2004	Knapp et al.
6,834,010	B1	12/2004	Qi et al.
6,857,181	B2	2/2005	Lo et al.
6,859,343	B1	2/2005	Alfoqaha et al.
6,859,997	B1	3/2005	Tong et al.
6,861,937	B1	3/2005	Feng et al.
6,870,712	B2	3/2005	Chen et al.
6,873,494	B2	3/2005	Chen et al.
6,873,547	B1	3/2005	Shi et al.
6,879,464	B2	4/2005	Sun et al.
6,888,184	B1	5/2005	Shi et al.
6,888,704	B1	5/2005	Diao et al.
6,891,697	B2	5/2005	Nakamura et al.
6,891,702	B1	5/2005	Tang
6,894,871	B2	5/2005	Alfoqaha et al.
6,894,877	B1	5/2005	Crue, Jr. et al.
6,903,900	B2	6/2005	Sato et al.
6,906,894	B2	6/2005	Chen et al.
6,909,578	B1	6/2005	Missell et al.
6,912,106	B1	6/2005	Chen et al.
6,934,113	B1	8/2005	Chen
6,934,129	B1	8/2005	Zhang et al.
6,940,688	B2	9/2005	Jiang et al.
6,942,824	B1	9/2005	Li
6,943,993	B2	9/2005	Chang et al.
6,944,938	B1	9/2005	Crue, Jr. et al.
6,947,255	B2	9/2005	Hsiao et al.
6,947,258	B1	9/2005	Li
6,950,266	B1	9/2005	McCaslin et al.
6,950,277	B1	9/2005	Nguy et al.
6,952,325	B2	10/2005	Sato et al.
6,954,332	B1	10/2005	Hong et al.
6,958,885	B1	10/2005	Chen et al.
6,961,221	B1	11/2005	Niu et al.
6,969,989	B1	11/2005	Mei
6,975,486	B2	12/2005	Chen et al.
6,987,643	B1	1/2006	Seagle
6,989,962	B1	1/2006	Dong et al.
6,989,972	B1	1/2006	Stoev et al.
6,995,949	B2	2/2006	Nakamura et al.
7,006,326	B2	2/2006	Okada et al.
7,006,327	B2	2/2006	Krounbi et al.
7,007,372	B1	3/2006	Chen et al.
7,012,832	B1	3/2006	Sin et al.
7,023,658	B1	4/2006	Knapp et al.
7,026,063	B2	4/2006	Ueno et al.
7,027,268	B1	4/2006	Zhu et al.
7,027,274	B1	4/2006	Sin et al.
7,035,046	B1	4/2006	Young et al.
7,041,985	B1	5/2006	Wang et al.
7,046,490	B1	5/2006	Ueno et al.
7,054,113	B1	5/2006	Seagle et al.
7,057,857	B1	6/2006	Niu et al.
7,059,868	B1	6/2006	Yan
7,070,698	B2	7/2006	Le
7,092,195	B1	8/2006	Liu et al.
7,100,266	B2	9/2006	Plumer et al.
7,110,289	B1	9/2006	Sin et al.
7,111,382	B1	9/2006	Knapp et al.
7,113,366	B1	9/2006	Wang et al.
7,114,241	B2	10/2006	Kubota et al.
7,116,517	B1	10/2006	He et al.
7,124,654	B1	10/2006	Davies et al.
7,126,788	B1	10/2006	Liu et al.
7,126,790	B1	10/2006	Liu et al.
7,131,346	B1	11/2006	Buttar et al.
7,133,252	B2	11/2006	Takano et al.
7,133,253	B1	11/2006	Seagle et al.
7,134,185	B1	11/2006	Knapp et al.
7,139,153	B2	11/2006	Hsiao et al.
7,154,715	B2	12/2006	Yamanaka et al.
7,159,302	B2	1/2007	Feldbaum et al.
7,170,725	B1	1/2007	Zhou et al.
7,177,117	B1	2/2007	Jiang et al.
7,185,415	B2	3/2007	Khera et al.
7,193,815	B1	3/2007	Stoev et al.
7,196,880	B1	3/2007	Anderson et al.
7,199,974	B1	4/2007	Alfoqaha
7,199,975	B1	4/2007	Pan
7,206,166	B2	4/2007	Notsuke et al.
7,211,339	B1	5/2007	Seagle et al.
7,212,379	B2	5/2007	Hsu et al.
7,212,384	B1	5/2007	Stoev et al.
7,238,292	B1	7/2007	He et al.
7,239,478	B1	7/2007	Sin et al.
7,245,454	B2	7/2007	Aoki et al.
7,248,431	B1	7/2007	Liu et al.
7,248,433	B1	7/2007	Stoev et al.
7,248,449	B1	7/2007	Seagle
7,251,878	B2	8/2007	Le et al.
7,253,992	B2	8/2007	Chen et al.
7,280,325	B1	10/2007	Pan
7,283,327	B1	10/2007	Liu et al.
7,284,316	B1	10/2007	Huai et al.
7,286,329	B1	10/2007	Chen et al.
7,289,303	B1	10/2007	Sin et al.
7,292,409	B1	11/2007	Stoev et al.
7,296,338	B2	11/2007	Le et al.
7,296,339	B1	11/2007	Yang et al.
7,307,814	B1	12/2007	Seagle et al.
7,307,818	B1	12/2007	Park et al.
7,310,204	B1	12/2007	Stoev et al.
7,318,947	B1	1/2008	Park et al.
7,324,304	B1	1/2008	Benakli et al.
7,333,295	B1	2/2008	Medina et al.
7,337,530	B1	3/2008	Stoev et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,342,752	B1	3/2008	Zhang et al.	
7,349,170	B1	3/2008	Rudman et al.	
7,349,179	B1	3/2008	He et al.	
7,354,664	B1	4/2008	Jiang et al.	
7,363,697	B1	4/2008	Dunn et al.	
7,369,359	B2	5/2008	Fujita et al.	
7,371,152	B1	5/2008	Newman	
7,372,665	B1	5/2008	Stoev et al.	
7,375,926	B1	5/2008	Stoev et al.	
7,379,269	B1	5/2008	Krounbi et al.	
7,386,933	B1	6/2008	Krounbi et al.	
7,389,577	B1	6/2008	Shang et al.	
7,392,577	B2	7/2008	Yazawa et al.	
7,417,832	B1	8/2008	Erickson et al.	
7,419,891	B1	9/2008	Chen et al.	
7,428,124	B1	9/2008	Song et al.	
7,430,095	B2	9/2008	Benakli et al.	
7,430,098	B1	9/2008	Song et al.	
7,436,620	B1	10/2008	Kang et al.	
7,436,638	B1	10/2008	Pan	
7,440,220	B1	10/2008	Kang et al.	
7,441,325	B2	10/2008	Gao et al.	
7,443,632	B1	10/2008	Stoev et al.	
7,444,740	B1	11/2008	Chung et al.	
7,464,457	B2	12/2008	Le et al.	
7,469,467	B2	12/2008	Gao et al.	
7,493,688	B1	2/2009	Wang et al.	
7,508,626	B2	3/2009	Ichihara et al.	
7,508,627	B1	3/2009	Zhang et al.	
7,522,377	B1	4/2009	Jiang et al.	
7,522,379	B1	4/2009	Krounbi et al.	
7,522,382	B1	4/2009	Pan	
7,535,675	B2	5/2009	Kimura et al.	
7,542,246	B1	6/2009	Song et al.	
7,551,406	B1	6/2009	Thomas et al.	
7,552,523	B1	6/2009	He et al.	
7,554,767	B1	6/2009	Hu et al.	
7,558,019	B2	7/2009	Le et al.	
7,580,222	B2	8/2009	Sasaki et al.	
7,583,466	B2	9/2009	Kermiche et al.	
7,595,967	B1	9/2009	Moon et al.	
7,639,451	B2 *	12/2009	Yatsu et al.	360/125.09
7,639,452	B2	12/2009	Mochizuki et al.	
7,639,457	B1	12/2009	Chen et al.	
7,643,246	B2	1/2010	Yazawa et al.	
7,660,080	B1	2/2010	Liu et al.	
7,663,839	B2	2/2010	Sasaki et al.	
7,672,079	B2	3/2010	Li et al.	
7,672,080	B1	3/2010	Tang et al.	
7,672,086	B1	3/2010	Jiang	
7,684,160	B1	3/2010	Erickson et al.	
7,688,546	B1	3/2010	Bai et al.	
7,691,434	B1	4/2010	Zhang et al.	
7,695,761	B1	4/2010	Shen et al.	
7,719,795	B2	5/2010	Hu et al.	
7,726,009	B1	6/2010	Liu et al.	
7,729,086	B1	6/2010	Song et al.	
7,729,087	B1	6/2010	Stoev et al.	
7,736,823	B1	6/2010	Wang et al.	
7,748,104	B2	7/2010	Bonhote et al.	
7,785,666	B1	8/2010	Sun et al.	
7,796,356	B1	9/2010	Fowler et al.	
7,796,360	B2	9/2010	Im et al.	
7,796,361	B2	9/2010	Sasaki et al.	
7,800,858	B1	9/2010	Bajikar et al.	
7,819,979	B1	10/2010	Chen et al.	
7,829,264	B1	11/2010	Wang et al.	
7,841,068	B2	11/2010	Chen et al.	
7,846,643	B1	12/2010	Sun et al.	
7,855,854	B2	12/2010	Hu et al.	
7,869,160	B1	1/2011	Pan et al.	
7,872,824	B1	1/2011	Macchioni et al.	
7,872,833	B2	1/2011	Hu et al.	
7,910,267	B1	3/2011	Zeng et al.	
7,911,735	B1	3/2011	Sin et al.	
7,911,737	B1	3/2011	Jiang et al.	
7,916,425	B2	3/2011	Sasaki et al.	
7,916,426	B2	3/2011	Hu et al.	
7,918,013	B1	4/2011	Dunn et al.	
7,924,528	B2	4/2011	Sasaki et al.	
7,968,219	B1	6/2011	Jiang et al.	
7,982,989	B1	7/2011	Shi et al.	
8,008,912	B1	8/2011	Shang	
8,012,804	B1	9/2011	Wang et al.	
8,015,692	B1	9/2011	Zhang et al.	
8,018,677	B1	9/2011	Chung et al.	
8,018,678	B1	9/2011	Zhang et al.	
8,024,748	B1	9/2011	Moravec et al.	
8,027,125	B2	9/2011	Lee et al.	
8,059,367	B2 *	11/2011	Lee et al.	360/125.3
8,072,705	B1	12/2011	Wang et al.	
8,074,345	B1	12/2011	Anguelouch et al.	
8,077,418	B1	12/2011	Hu et al.	
8,077,434	B1	12/2011	Shen et al.	
8,077,435	B1	12/2011	Liu et al.	
8,077,557	B1	12/2011	Hu et al.	
8,079,135	B1	12/2011	Shen et al.	
8,081,403	B1	12/2011	Chen et al.	
8,091,210	B1	1/2012	Sasaki et al.	
8,097,846	B1	1/2012	Anguelouch et al.	
8,104,166	B1	1/2012	Zhang et al.	
8,116,033	B2	2/2012	Kameda et al.	
8,116,043	B2	2/2012	Leng et al.	
8,116,171	B1	2/2012	Lee	
8,125,732	B2	2/2012	Bai et al.	
8,125,856	B1	2/2012	Li et al.	
8,134,794	B1	3/2012	Wang	
8,136,224	B1	3/2012	Sun et al.	
8,136,225	B1	3/2012	Zhang et al.	
8,136,805	B1	3/2012	Lee	
8,141,235	B1	3/2012	Zhang	
8,146,236	B1	4/2012	Luo et al.	
8,149,536	B1	4/2012	Yang et al.	
8,151,441	B1	4/2012	Rudy et al.	
8,163,185	B1	4/2012	Sun et al.	
8,164,760	B2	4/2012	Willis	
8,164,855	B1	4/2012	Gibbons et al.	
8,164,864	B2	4/2012	Kaiser et al.	
8,165,709	B1	4/2012	Rudy	
8,166,631	B1	5/2012	Tran et al.	
8,166,632	B1	5/2012	Zhang et al.	
8,169,473	B1	5/2012	Yu et al.	
8,171,618	B1	5/2012	Wang et al.	
8,179,636	B1	5/2012	Bai et al.	
8,184,399	B2	5/2012	Wu et al.	
8,191,237	B1	6/2012	Luo et al.	
8,194,365	B1	6/2012	Leng et al.	
8,194,366	B1	6/2012	Li et al.	
8,196,285	B1	6/2012	Zhang et al.	
8,200,054	B1	6/2012	Li et al.	
8,203,800	B2	6/2012	Li et al.	
8,208,350	B1	6/2012	Hu et al.	
8,220,140	B1	7/2012	Wang et al.	
8,222,599	B1	7/2012	Chien	
8,225,488	B1	7/2012	Zhang et al.	
8,227,023	B1	7/2012	Liu et al.	
8,228,633	B1	7/2012	Tran et al.	
8,231,796	B1	7/2012	Li et al.	
8,233,233	B1 *	7/2012	Shen et al.	360/125.03
8,233,234	B2	7/2012	Hsiao et al.	
8,233,235	B2	7/2012	Chen et al.	
8,233,248	B1	7/2012	Li et al.	
8,248,728	B2	8/2012	Yamaguchi et al.	
8,248,896	B1	8/2012	Yuan et al.	
8,254,060	B1	8/2012	Shi et al.	
8,257,597	B1	9/2012	Guan et al.	
8,259,410	B1	9/2012	Bai et al.	
8,259,539	B1	9/2012	Hu et al.	
8,262,918	B1	9/2012	Li et al.	
8,262,919	B1	9/2012	Luo et al.	
8,264,792	B2	9/2012	Bai et al.	
8,264,797	B2	9/2012	Emley	
8,264,798	B1	9/2012	Guan et al.	
8,270,109	B2	9/2012	Ohtsu	

(56) **References Cited**

U.S. PATENT DOCUMENTS

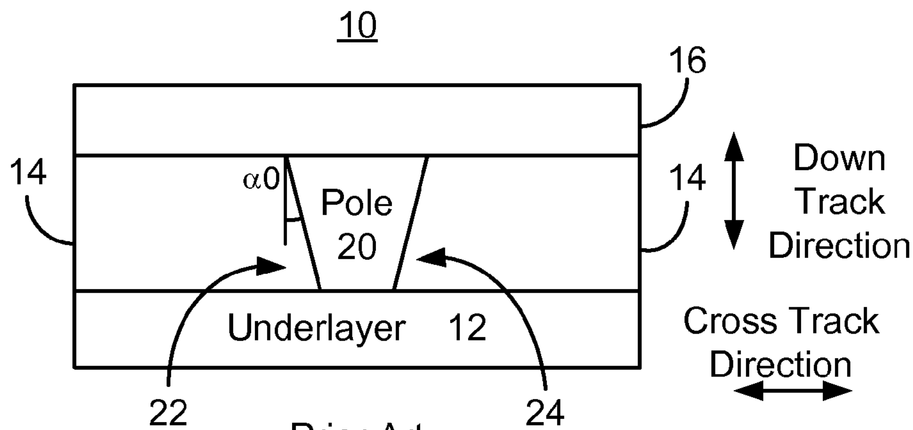
8,270,126	B1	9/2012	Roy et al.
8,276,258	B1	10/2012	Tran et al.
8,277,669	B1	10/2012	Chen et al.
8,279,719	B1	10/2012	Hu et al.
8,284,517	B1	10/2012	Sun et al.
8,288,204	B1	10/2012	Wang et al.
8,289,649	B2	10/2012	Sasaki et al.
8,289,821	B1	10/2012	Huber
8,291,743	B1	10/2012	Shi et al.
8,305,711	B2	11/2012	Li et al.
8,307,539	B1	11/2012	Rudy et al.
8,307,540	B1	11/2012	Tran et al.
8,308,921	B1	11/2012	Hiner et al.
8,310,785	B1	11/2012	Zhang et al.
8,310,901	B1	11/2012	Batra et al.
8,315,019	B1	11/2012	Mao et al.
8,316,527	B2	11/2012	Hong et al.
8,320,076	B1	11/2012	Shen et al.
8,320,077	B1	11/2012	Tang et al.
8,320,219	B1	11/2012	Wolf et al.
8,320,220	B1	11/2012	Yuan et al.
8,320,722	B1	11/2012	Yuan et al.
8,322,022	B1	12/2012	Yi et al.
8,322,023	B1	12/2012	Zeng et al.
8,325,569	B1	12/2012	Shi et al.
8,333,008	B1	12/2012	Sin et al.
8,334,093	B2	12/2012	Zhang et al.
8,336,194	B2	12/2012	Yuan et al.
8,339,738	B1	12/2012	Tran et al.
8,341,826	B1	1/2013	Jiang et al.
8,343,319	B1	1/2013	Li et al.
8,343,364	B1	1/2013	Gao et al.
8,347,488	B2	1/2013	Hong et al.
8,349,195	B1	1/2013	Si et al.
8,351,307	B1	1/2013	Wolf et al.
8,357,244	B1	1/2013	Zhao et al.
8,373,945	B1	2/2013	Luo et al.
8,375,564	B1	2/2013	Luo et al.
8,375,565	B2	2/2013	Hu et al.
8,381,391	B2	2/2013	Park et al.
8,385,157	B1	2/2013	Champion et al.
8,385,158	B1	2/2013	Hu et al.
8,394,280	B1	3/2013	Wan et al.
8,400,731	B1	3/2013	Li et al.
8,404,128	B1	3/2013	Zhang et al.
8,404,129	B1	3/2013	Luo et al.
8,405,930	B1	3/2013	Li et al.
8,409,453	B1	4/2013	Jiang et al.
8,413,317	B1	4/2013	Wan et al.
8,416,540	B1	4/2013	Li et al.
8,419,953	B1	4/2013	Su et al.
8,419,954	B1	4/2013	Chen et al.
8,422,176	B1	4/2013	Leng et al.
8,422,342	B1	4/2013	Lee
8,422,841	B1	4/2013	Shi et al.
8,424,192	B1	4/2013	Yang et al.
8,441,756	B1	5/2013	Sun et al.
8,443,510	B1	5/2013	Shi et al.
8,444,866	B1	5/2013	Guan et al.
8,449,948	B2	5/2013	Medina et al.
8,451,556	B1	5/2013	Wang et al.
8,451,563	B1	5/2013	Zhang et al.
8,454,846	B1	6/2013	Zhou et al.
8,455,119	B1	6/2013	Jiang et al.
8,456,961	B1	6/2013	Wang et al.
8,456,963	B1	6/2013	Hu et al.
8,456,964	B1	6/2013	Yuan et al.
8,456,966	B1	6/2013	Shi et al.
8,456,967	B1	6/2013	Mallary
8,458,892	B2	6/2013	Si et al.
8,462,592	B1	6/2013	Wolf et al.
8,468,682	B1	6/2013	Zhang
8,472,288	B1	6/2013	Wolf et al.
8,480,911	B1	7/2013	Osugi et al.
8,486,285	B2	7/2013	Zhou et al.
8,486,286	B1	7/2013	Gao et al.
8,488,272	B1	7/2013	Tran et al.
8,491,801	B1	7/2013	Tanner et al.
8,491,802	B1	7/2013	Gao et al.
8,493,693	B1	7/2013	Zheng et al.
8,493,695	B1	7/2013	Kaiser et al.
8,495,813	B1	7/2013	Hu et al.
8,498,084	B1	7/2013	Leng et al.
8,506,828	B1	8/2013	Osugi et al.
8,514,517	B1	8/2013	Batra et al.
8,518,279	B1	8/2013	Wang et al.
8,518,832	B1	8/2013	Yang et al.
8,520,336	B1	8/2013	Liu et al.
8,520,337	B1	8/2013	Liu et al.
8,524,068	B2	9/2013	Medina et al.
8,526,275	B1	9/2013	Yuan et al.
8,531,801	B1	9/2013	Xiao et al.
8,532,450	B1	9/2013	Wang et al.
8,533,937	B1	9/2013	Wang et al.
8,537,494	B1	9/2013	Pan et al.
8,537,495	B1	9/2013	Luo et al.
8,537,502	B1	9/2013	Park et al.
8,545,999	B1	10/2013	Leng et al.
8,547,659	B1	10/2013	Bai et al.
8,547,667	B1	10/2013	Roy et al.
8,547,730	B1	10/2013	Shen et al.
8,555,486	B1	10/2013	Medina et al.
8,559,141	B1	10/2013	Pakala et al.
8,563,146	B1	10/2013	Zhang et al.
8,565,049	B1	10/2013	Tanner et al.
8,576,517	B1	11/2013	Tran et al.
8,578,594	B2	11/2013	Jiang et al.
8,582,238	B1	11/2013	Liu et al.
8,582,241	B1	11/2013	Yu et al.
8,582,253	B1	11/2013	Zheng et al.
8,588,039	B1	11/2013	Shi et al.
8,593,914	B2	11/2013	Wang et al.
8,597,528	B1	12/2013	Roy et al.
8,599,520	B1	12/2013	Liu et al.
8,599,657	B1	12/2013	Lee
8,603,593	B1	12/2013	Roy et al.
8,607,438	B1	12/2013	Gao et al.
8,607,439	B1	12/2013	Wang et al.
8,611,035	B1	12/2013	Bajikar et al.
8,611,054	B1	12/2013	Shang et al.
8,611,055	B1	12/2013	Pakala et al.
8,614,864	B1	12/2013	Hong et al.
8,619,512	B1	12/2013	Yuan et al.
8,625,233	B1	1/2014	Ji et al.
8,625,941	B1	1/2014	Shi et al.
8,628,672	B1	1/2014	Si et al.
8,630,068	B1	1/2014	Mauri et al.
8,634,280	B1	1/2014	Wang et al.
8,638,529	B1	1/2014	Leng et al.
8,643,980	B1	2/2014	Fowler et al.
8,649,123	B1	2/2014	Zhang et al.
8,665,561	B1	3/2014	Knutson et al.
8,670,211	B1	3/2014	Sun et al.
8,670,213	B1	3/2014	Zeng et al.
8,670,214	B1	3/2014	Knutson et al.
8,670,294	B1	3/2014	Shi et al.
8,670,295	B1	3/2014	Hu et al.
8,675,318	B1	3/2014	Ho et al.
8,675,455	B1	3/2014	Krichevsky et al.
8,681,594	B1	3/2014	Shi et al.
8,689,430	B1	4/2014	Chen et al.
8,693,141	B1	4/2014	Elliott et al.
8,703,397	B1	4/2014	Zeng et al.
8,705,205	B1	4/2014	Li et al.
2003/0076630	A1	4/2003	Sato et al.
2004/0061988	A1	4/2004	Matono et al.
2004/0184191	A1	9/2004	Ichihara et al.
2005/0117251	A1	6/2005	Matono et al.
2006/0044677	A1	3/2006	Li et al.
2006/0158779	A1	7/2006	Ota et al.
2006/0174474	A1	8/2006	Le
2006/0225268	A1	10/2006	Le et al.
2006/0288565	A1	12/2006	Le et al.
2007/0211380	A1	9/2007	Akimoto et al.

(56) **References Cited**

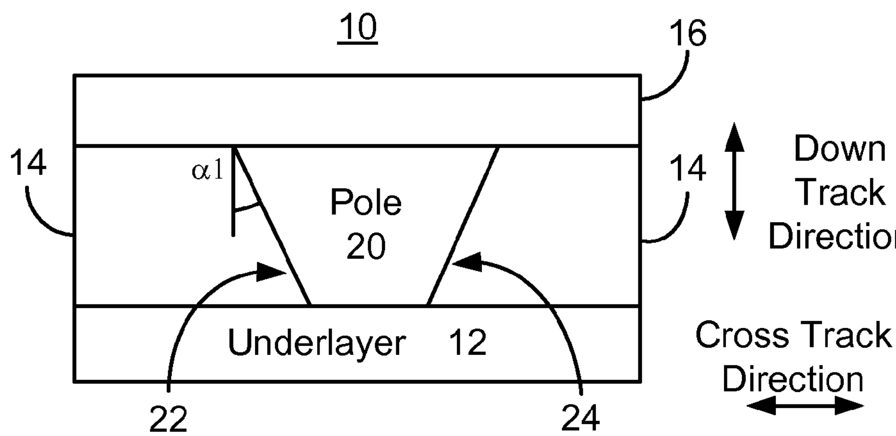
U.S. PATENT DOCUMENTS

2007/0236834	A1	10/2007	Toma et al.
2007/0247746	A1	10/2007	Kim et al.
2007/0258167	A1	11/2007	Allen et al.
2007/0263324	A1	11/2007	Allen et al.
2007/0283557	A1	12/2007	Chen et al.
2008/0002309	A1	1/2008	Hsu et al.
2008/0151437	A1	6/2008	Chen et al.
2009/0279206	A1	11/2009	Yang et al.
2010/0146773	A1	6/2010	Li et al.
2010/0277832	A1	11/2010	Bai et al.
2010/0290157	A1	11/2010	Zhang et al.
2011/0051293	A1	3/2011	Bai et al.
2011/0086240	A1	4/2011	Xiang et al.
2011/0222188	A1	9/2011	Etoh et al.
2012/0111826	A1	5/2012	Chen et al.
2012/0216378	A1	8/2012	Emley et al.
2012/0237878	A1	9/2012	Zeng et al.
2012/0268845	A1	10/2012	Sahoo et al.
2012/0298621	A1	11/2012	Gao
2013/0216702	A1	8/2013	Kaiser et al.
2013/0216863	A1	8/2013	Li et al.
2013/0257421	A1	10/2013	Shang et al.

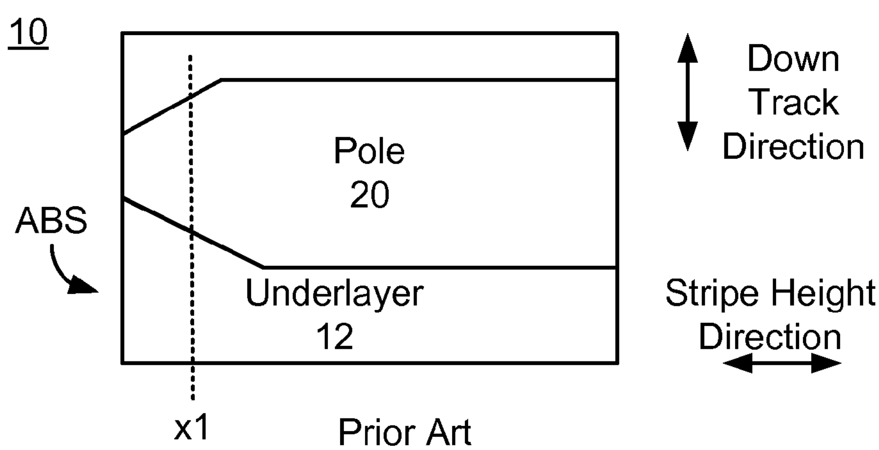
* cited by examiner



Prior Art
ABS View
F1G. 1A



Prior Art
FIG. 1B



Prior Art
FIG. 1C

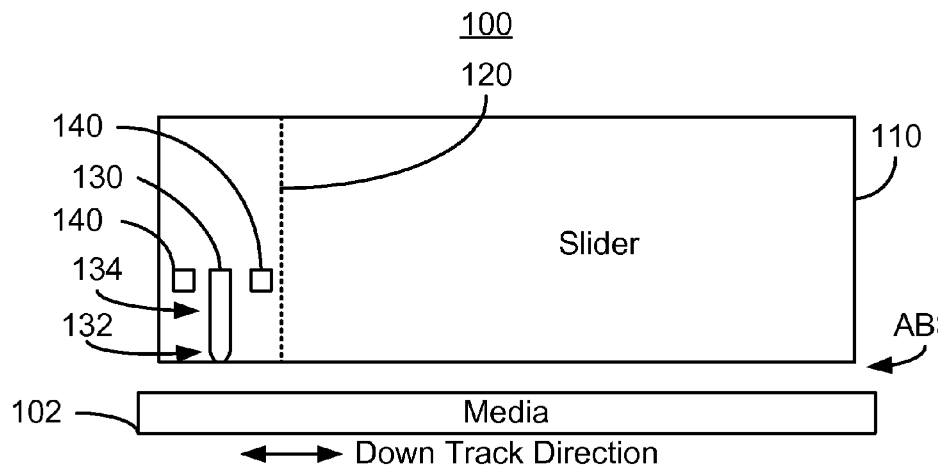
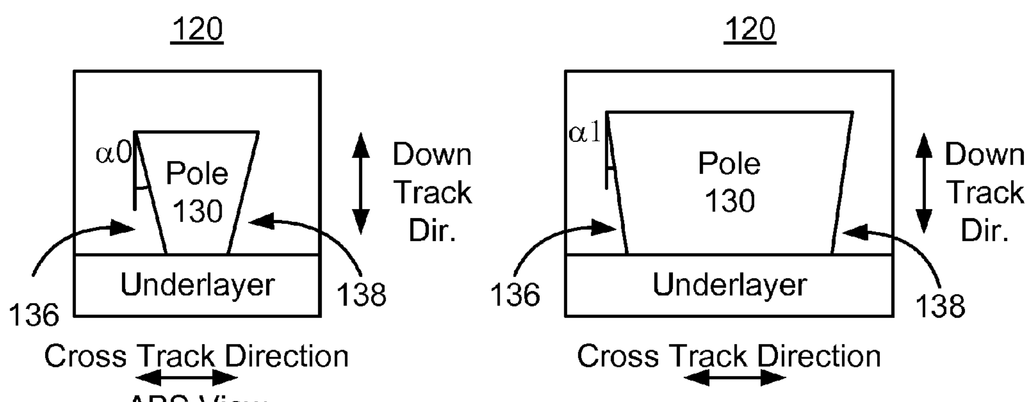


FIG. 2



F1G. 3A

F1G. 3B

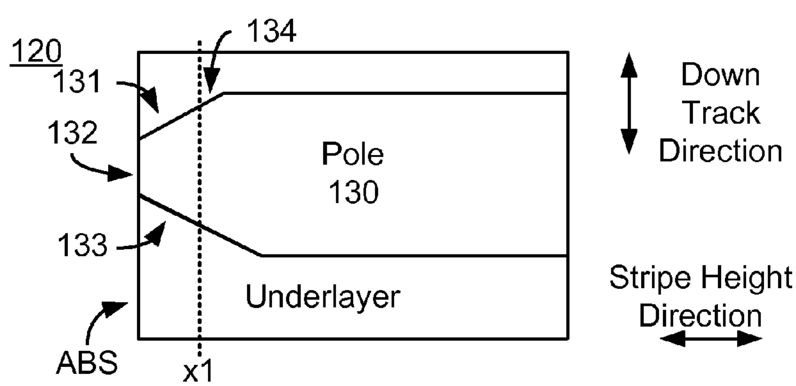


FIG. 3C

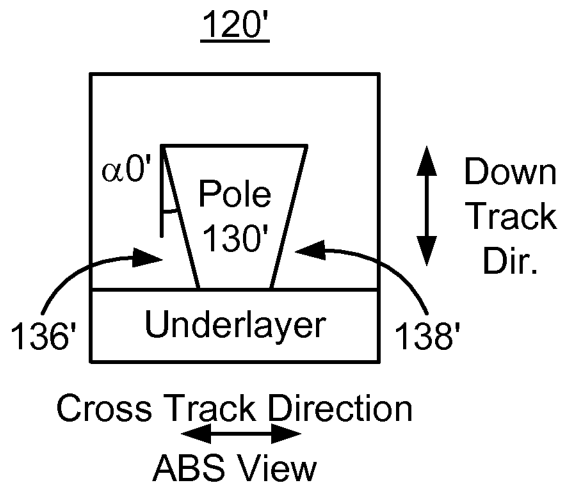


FIG. 4A

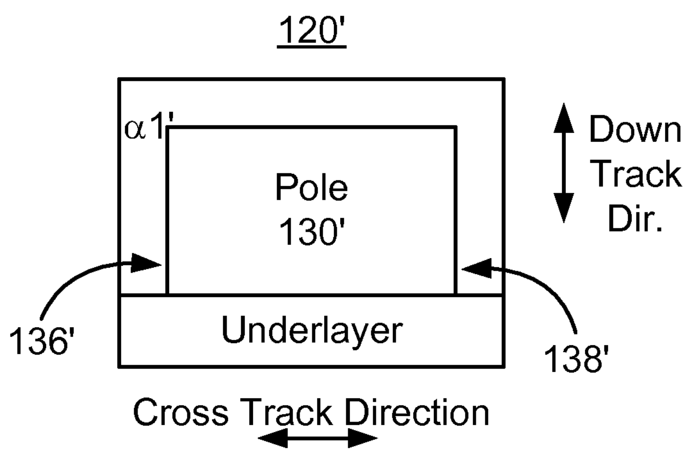


FIG. 4B

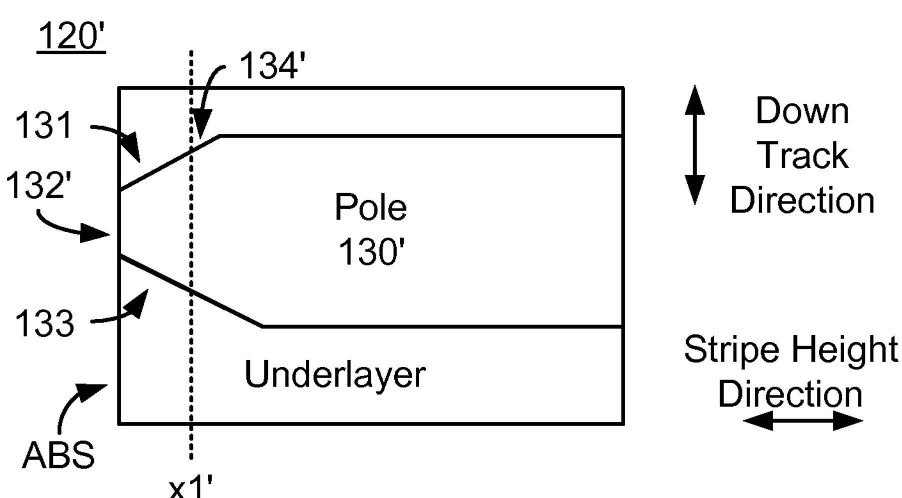


FIG. 4C

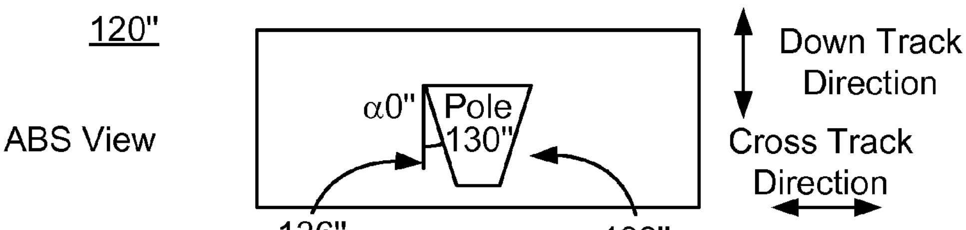


FIG. 5A

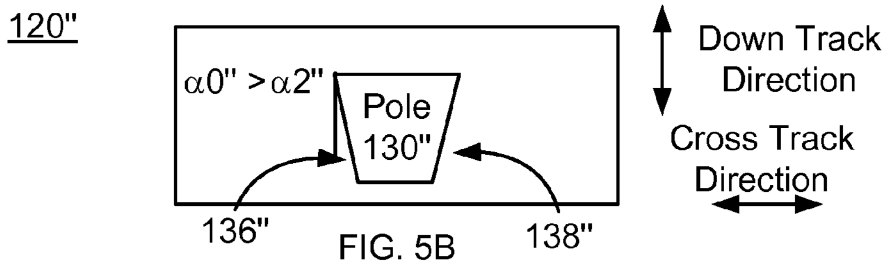


FIG. 5B

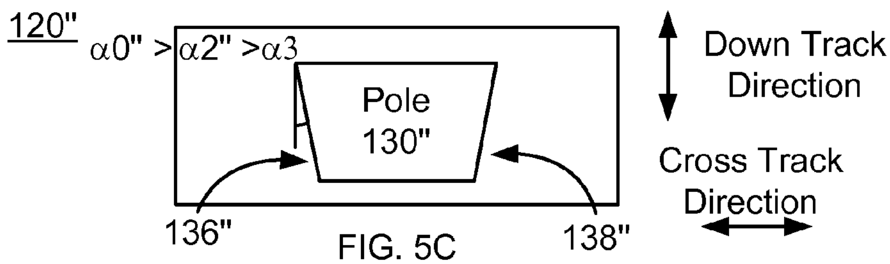


FIG. 5C

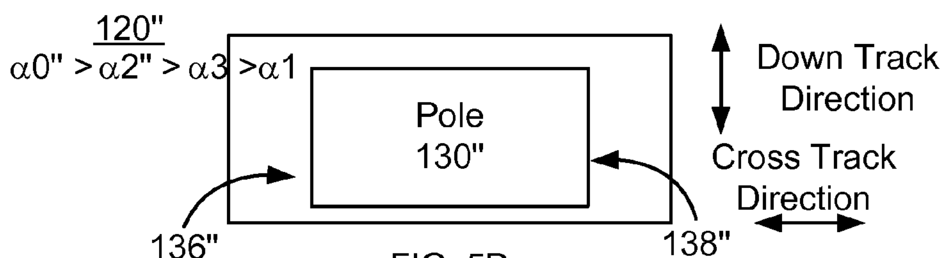


FIG. 5D

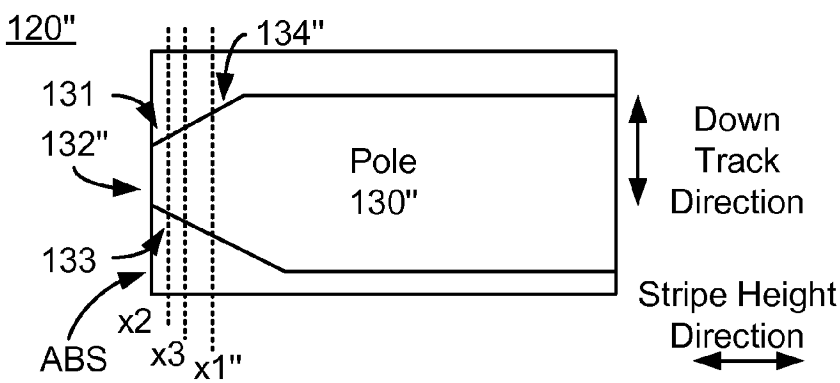


FIG. 5E

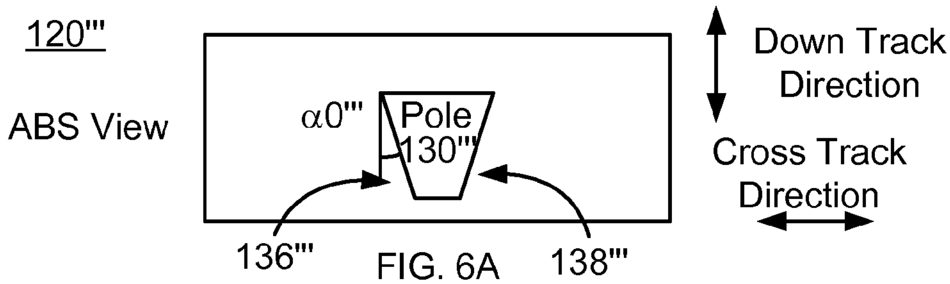


FIG. 6A

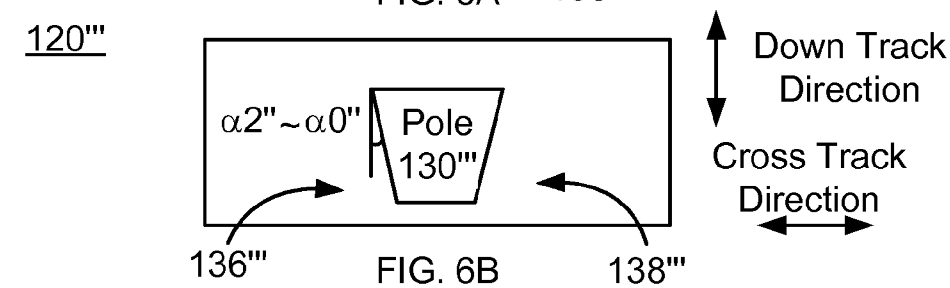


FIG. 6B

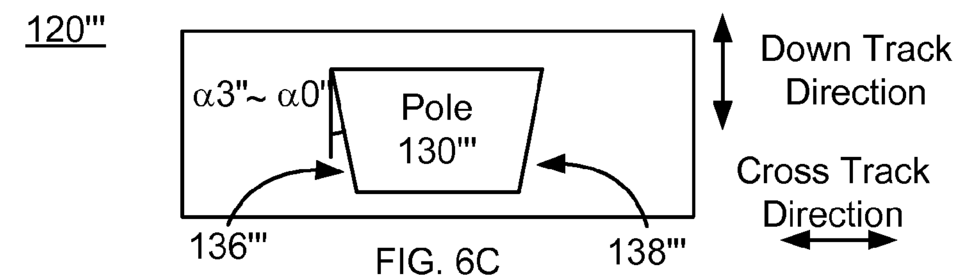


FIG. 6C

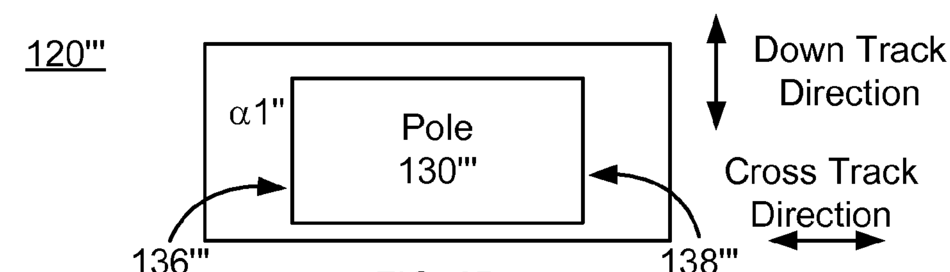


FIG. 6D

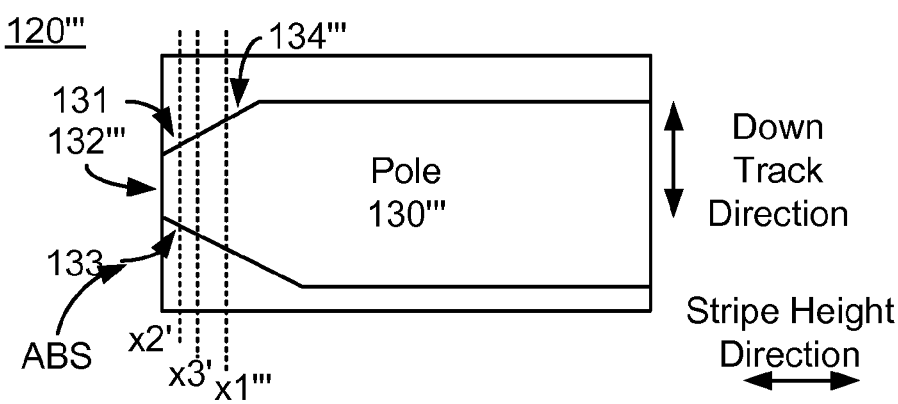


FIG. 6E

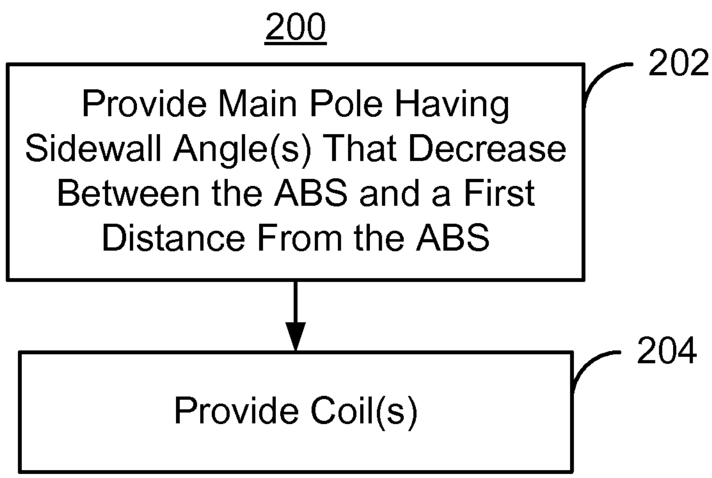

200
Provide Main Pole Having Sidewall Angle(s) That Decrease Between the ABS and a First Distance From the ABS
202
Provide Coil(s)
204

FIG. 7

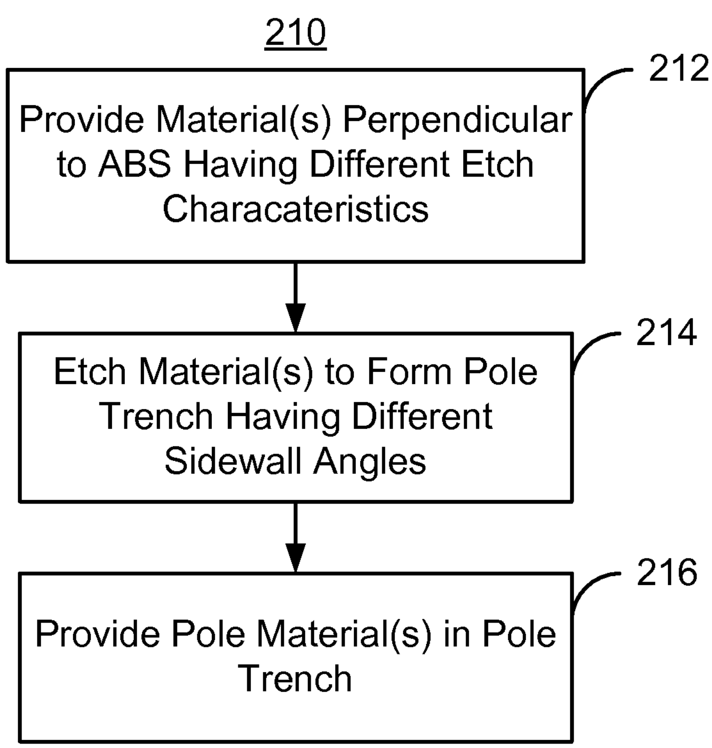

210
Provide Material(s) Perpendicular to ABS Having Different Etch Characateristics
212
Etch Material(s) to Form Pole Trench Having Different Sidewall Angles
214
Provide Pole Material(s) in Pole Trench
216

FIG. 8

MAGNETIC RECORDING WRITE TRANSDUCER HAVING AN IMPROVED SIDEWALL ANGLE PROFILE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to provisional U.S. Patent Application Ser. No. 61/876,340, filed on Sep. 11, 2013, which is hereby incorporated by reference in its entirety.

BACKGROUND

FIGS. **1**A, **1**B and **1**C depict ABS, yoke and side views of a conventional magnetic recording head **10**. The magnetic recording transducer **10** may be a perpendicular magnetic recording (PMR) head. The conventional magnetic recording transducer **10** may be a part of a merged head including the write transducer **10** and a read transducer (not shown). Alternatively, the magnetic recording head may be a write head including only the write transducer **10**. Although termed a yoke view, the view shown in FIG. **1**B is taken along the surface parallel to the ABS a distance **x1** from the ABS. This surface is depicted as a dotted line in FIG. **1**C.

The main pole **20** resides on an underlayer **12** and includes sidewalls **22** and **24**. The sidewalls **22** and **24** of the conventional main pole **20** form an angle $\alpha 0$ with the down track direction at the ABS and an angle $\alpha 1$ with the down track direction at the distance **x1** from the ABS. As can be seen in FIGS. **1**A and **1**B, portions of the main pole **20** recessed from the ABS in the stripe height direction are wider in the cross track direction than at the ABS. In addition, the angle between the sidewalls **22** and **24** and the down track direction increases. Thus, $\alpha 1$ is greater than $\alpha 0$. For example, if $\alpha 0$ is on the order of 13°, then $\alpha 1$ may be 25°.

Although the conventional magnetic recording head **10** functions, there are drawbacks. In particular, the conventional magnetic recording head **10** may not perform sufficiently at higher recording densities. For example, the write field of the conventional main pole **20** may not have a sufficiently high magnitude write field to meet particular standards. Accordingly, what is needed is a system and method for improving the performance of a magnetic recording head.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIGS. **1**A-**1**C depict ABS, yoke and side view of a conventional magnetic recording head.

FIG. **2** depicts an exemplary embodiment of a magnetic recording disk drive.

FIGS. **3**A, **3**B and **3**C depict ABS, yoke and side views of an exemplary embodiment of a magnetic recording transducer.

FIGS. **4**A, **4**B and **4**C depict ABS, yoke and side views of an exemplary embodiment of a magnetic recording transducer.

FIGS. **5**A, **5**B, **5**C, **5**D and **5**E depict ABS and various views and a side view of an exemplary embodiment of a magnetic recording transducer.

FIGS. **6**A, **6**B, **6**C, **6**D and **6**E depict ABS and various views and a side view of an exemplary embodiment of a magnetic recording transducer.

FIG. **7** depicts a flow chart of an exemplary embodiment of a method for providing magnetic recording transducer.

FIG. **8** depicts a flow chart of an exemplary embodiment of a method for fabricating a portion of a magnetic recording transducer.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **2** depicts a side view of an exemplary embodiment of a portion of a disk drive **100** including a write transducer **120**. FIGS. **3**A, **3**B and **3**C depict ABS, yoke and side views of the transducer **120**. For clarity, FIGS. **2**, **3**A, **3**B and **3**C are not to scale. For simplicity not all portions of the disk drive **100** and transducer **120** are shown. In addition, although the disk drive **100** and transducer **120** are depicted in the context of particular components other and/or different components may be used. For example, circuitry used to drive and control various portions of the disk drive **100** is not shown. For simplicity, only single components **102**, **110**, **120** and **130** are shown. However, multiples of each components **102**, **110**, **120** and/or and their sub-components, might be used. The disk drive **100** may be a PMR disk drive. However, in other embodiments, the disk drive **100** may be configured for other types of magnetic recording.

The disk drive **100** includes media **102**, a slider **110** and a write transducer **120**. Additional and/or different components may be included in the disk drive **100**. Although not shown, the slider **110** and thus the transducer **120** are generally attached to a suspension (not shown).

The transducer **120** is fabricated on the slider **110** and includes an air-bearing surface (ABS) proximate to the media **102** during use. In general, the disk drive **100** includes a write transducer **120** and a read transducer (not shown). However, for clarity, only the write transducer **120** is shown. The transducer **120** includes a main pole **130** and coils **140**. In other embodiments, different and/or additional components may be used in the write transducer **120**.

The coil(s) **140** are used to energize the main pole **130**. Two turns **140** are depicted in FIG. **2**. Another number of turns may, however, be used. Note that only a portion of the coil(s) **140** is shown in FIG. **2**. If, for example, the coil(s) **140** form a helical coil, then additional portion(s) of the coil(s) **140** may be located on the opposite side of the main pole **130** as is shown. If the coil(s) **140** is a spiral, or pancake, coil, then additional portions of the coil(s) **140** may be located further from the ABS. Further, additional coils may also be used.

The main pole **130** includes a pole tip region **132** close to the ABS and a yoke region **134** recessed from the ABS. The pole tip region **132** is shown as having top and bottom bevels **131** and **133**, respectively, near the ABS. In addition, the pole tip region **134** includes sidewalls **136** and **138** in the cross track direction. The sidewalls are configured such that the pole **130** has a bottom and a top wider than the bottom.

The sidewalls **136** and **138** form sidewall angles with the down track direction. At the ABS, the sidewall **136** forms sidewall angle $\alpha 0$ with respect to the down track direction. In some embodiments, the sidewalls **136** and **138** are symmetric. Thus, although not labeled, the sidewall **138** would form substantially the same sidewall angle with the down track direction as the sidewall **136**. In some embodiments, $\alpha 0$ is not more than fourteen degrees. In some such embodiments, $\alpha 0$ is at least twelve degrees. For example, $\alpha 0$ may be nominally 13.5°. At a distance **x1** recessed from the ABS, the sidewall **136** forms sidewall angle $\alpha 1$ with the down track direction. The sidewall angle $\alpha 1$ is less than $\alpha 0$ at **x1**. For example, if $\alpha 0$ is 12-14 degrees, then $\alpha 1$ is greater than or equal to zero degrees and not more than 12-14 degrees. In some embodiments, $\alpha 1$ is at least seven degrees. Further, the distance **x1** may vary. In some embodiments, **x1** is desired to be not more than the distance which the bevel **131** or **133** extends into the ABS. For example, in some embodiments, **x1** is not more than two hundred nanometers. In some embodiments, **x1** is desired to be closer to the ABS. In some embodiments, **x1** may be not more than eighty nanometers. For example, **x1** may be at least 30 nm from the ABS if, for example, the processing tolerance in the location of **x1** is 10 nm (corresponding to a 3σ of 30 nm). In general, **x1** is desired to be sufficiently large that the sidewall angle α**0** at the ABS remains unchanged. The manner in which the sidewall angle changes from α**0** to α**1** may vary. The sidewall angle may monotonically decrease between the ABS and **x1**. In some embodiments, the sidewall angle smoothly varies from α**0** to α**1**. In other embodiments, the sidewall angle may change in step function(s) from α**0** to α**1**. Although described herein as step function(s), one of ordinary skill in the art will recognize that there are processing and/or other limitations or considerations. Therefore, the transitions of such a "step" function may be rounded and/or transitions may not be sharp. Thus, as used herein, a step function may not be identical to a purely mathematical step function. This may occur at **x1** or between the ABS and **x1**. In other embodiments, the change may be linear or piece-wise linear. In other embodiments the change may be in accordance with a higher order function including but not limited to a quadratic function. However, other configurations are possible. Although described herein in terms of particular mathematical functions, one of ordinary skill in the art will recognize that there are processing and/or other limitations or considerations. Consequently, the actual profile of the main poles may not precisely follow the mathematical functions used herein.

The magnetic disk drive **100** may exhibit improved performance. Because of the variation in the sidewall angle, the magnetic field generated by the main pole **130** and used to write to the media **102** may be enhanced. The reverse overwrite gain may also be improved. The gradient in the magnetic field may also be improved while maintaining substantially the same side fields. As a result, adjacent track interference may not be adversely affected. Further, the pole tip region **132** of the main pole **130** may have an increased magnetic volume. Stated differently, the pole tip region **132** may include more magnetic material. As a result, the cross track magnetic anisotropy may be improved and domain lockup issues mitigated. Thus, performance of the disk drive **100** may be improved.

FIGS. **4**A, **4**B and **4**C depict ABS, yoke and side views of a transducer **120'** analogous to the transducer **120** in disk drive **100**. For clarity, FIGS. **4**A, **4**B and **4**C are not to scale. For simplicity not all portions of the transducer **120'** are shown. Because the magnetic recording transducer **120'** is analogous to the transducer **120** in the magnetic disk drive **100**, analogous components have similar labels.

The transducer **120'** includes a main pole **130'** having sidewalls **136'** and **138'** that are analogous to the main pole **130** and sidewalls **136** and **138**, respectively. The main pole **130'** also includes a pole tip region **132'** and a yoke region **134'** that are analogous to the pole tip **132** and yoke **134**, respectively. The pole tip region **132'** is shown as having top and bottom bevels **131** and **133**, respectively that are analogous to the bevels **131** and **133** depicted in FIGS. **2** and **3**C. The sidewalls **136'** and **138'** are configured such that the pole **130'** has a bottom and a top wider than the bottom.

The sidewalls **136'** and **138'** form sidewall angles α**0'** and α**1'** with respect to the down track direction at the ABS and **x1'**, respectively. In some embodiments, α**0'** has a size range analogous to α**0**. For example, α**0'** may be at least twelve degrees and not more than fourteen degrees and in some embodiments may be nominally 13.5°. The sidewall angle α**1'** is less than α**0'** at **x1'**. In the embodiment shown, α**1'** is zero degrees. The distance **x1'** may also vary in a manner analogous to **x1**. In some embodiments, **x1'** is desired to be not more than the distance which the bevel **131** or **133** extends into the ABS. For example, in some embodiments, **x1'** is not more than two hundred nanometers. In some embodiments, **x1'** is desired to be closer to the ABS. In some embodiments, **x1'** is not more than eighty nanometers. For example, **x1'** may be at least 30 nm from the ABS if, for example, the processing tolerance in location of **x1'** is 10 nm. In general, **x1'** is desired to be sufficiently large that the sidewall angle α**0'** at the ABS remains unchanged. The manner in which the sidewall angle changes from α**0'** to α**1'** may vary. The sidewall angle may monotonically decrease between the ABS and **x1'**. In some embodiments, the sidewall angle smoothly varies from α**0'** to α**1'**. In other embodiments, the sidewall angle may change in step function(s) from α**0'** to α**1'**. These change(s) may occur at **x1'** or between the ABS and **x1'**. In other embodiments, the change may be linear or piece-wise linear. In other embodiments the change may be in accordance with a higher order function including but not limited to a quadratic function. However, other configurations are possible. Although the variation in sidewall angle is described herein in terms of step function(s) and other mathematical functions, one of ordinary skill in the art will recognize that there exist processing and/or other limitations or considerations. Therefore, the transitions of such a "step" function may be rounded and/or transitions may not be sharp. Similarly, "linear" regions may not be perfectly straight. Thus, the actual profile of the main poles may not precisely follow the mathematical functions used herein.

The magnetic transducer **120'** may exhibit improved performance for analogous reasons to those discussed above. Because of the variations in the sidewall angle, the magnetic field generated by the main pole **130'** may be increased. The reverse overwrite gain may also be improved. The gradient in the magnetic field may also be improved while maintaining substantially the same side fields. As a result, adjacent track interference may not be adversely affected. Further, the pole tip region **132'** of the main pole **130'** may have an increased magnetic volume. As a result, the cross track magnetic anisotropy may be improved and domain lockup issues mitigated. Thus, performance of the disk drive **100** may be improved.

FIGS. **5**A, **5**B, **5**C and **5**E depict ABS, first pole tip, second pole tip, yoke and side views, respectively, of a transducer **120"** analogous to the transducers **120/120'** and disk drive **100**. For clarity, FIGS. **5**A-**5**E are not to scale. For simplicity not all portions of the transducer **120"** are shown. Because the magnetic recording transducer **120"** is analogous to the transducers **120/120'** in the magnetic disk drive **100**, analogous components have similar labels.

The transducer **120"** includes a main pole **130"** having sidewalls **136"** and **138"** that are analogous to the main pole **130/130'** and sidewalls **136/136'** and **138/138'**, respectively. The main pole **130"** also includes a pole tip region **132"** and a yoke region **134"** that are analogous to the pole tip **132/132'** and yoke **134/134'**, respectively. The pole tip region **132"** is shown as having top and bottom bevels **131** and **133**, respectively, that are analogous to the bevels **131** and **133** depicted in FIGS. **2**, **3**C and **4**C. The sidewalls **136"** and **138"** are configured such that the pole **130"** has a bottom and a top wider than the bottom.

The sidewalls **136"** and **138"** form sidewall angles α**0"** and α**1"** with respect to the down track direction at the ABS and **x1"**, respectively. In addition, the sidewalls **136"** and **138"** form sidewall angles $\alpha2$ and $\alpha3$ at positions x2 and x3. In the embodiment shown, $\alpha2$ and $\alpha3$ are between $\alpha0$ and $\alpha1$. Thus, the sidewall angle monotonically decreases from the ABS to x2, x3 and x1. In some embodiments, $\alpha0''$ has a size range analogous to $\alpha0$. For example, $\alpha0''$ may be at least twelve degrees and not more than fourteen degrees and in some embodiments may be nominally 13.5°. The sidewall angle $\alpha1''$ is less than $\alpha0''$ at x1". In the embodiment shown, $\alpha1''$ is zero degrees. The distance x1" may also vary in a manner analogous to x1/x1'. In some embodiments, x1" is desired to be not more than the distance which the bevel **131** or **133** extends into the ABS. For example, in some embodiments, x1" is not more than two hundred nanometers. In some embodiments, x1" is desired to be closer to the ABS as described above. In general, x1" is desired to be sufficiently large that the sidewall angle $\alpha0''$ at the ABS remains unchanged. The manner in which the sidewall angle changes from $\alpha0''$ to $\alpha1''$ may vary. In some embodiments, the sidewall angle smoothly varies from $\alpha0'$ to $\alpha1'$. In other embodiments, the sidewall angle may change in a manner analogous to step function(s) from $\alpha0''$ to $\alpha1''$. These change(s) may occur at x2, x3 and x1". For example, $\alpha2$ may be 11° and x2 may be approximately 50 nm within tolerances. Similarly, $\alpha3$ may be 7° and x3 may be one hundred nanometers within tolerances. However, in other embodiments, other distances and other sidewall angles may be possible. In other embodiments, the change may be linear or piece-wise linear. For example, a new slope for each line segment may occur at x2, x3 and x1. In other embodiments the change may be in accordance with a higher power function including but not limited to a quadratic function. However, other configurations are possible. Although the variation in sidewall angle is described herein in terms of step function(s) and other mathematical functions, one of ordinary skill in the art will recognize that there exist processing and/or other limitations or considerations. Therefore, the transitions of such a "step" function may be rounded and/or transitions may not be sharp. Similarly, "linear" regions may not be perfectly straight. Thus, the actual profile of the main poles may not precisely follow the mathematical functions used herein.

The magnetic transducer **120"** may exhibit improved performance for analogous reasons to those discussed above. Because of the variations in the sidewall angle, the magnetic field generated by the main pole **130"** may be increased. The reverse overwrite gain may also be improved. The gradient in the magnetic field may also be improved while maintaining substantially the same side fields. As a result, adjacent track interference may not be adversely affected. Further, the pole tip region **132"** of the main pole **130"** may have an increased magnetic volume. As a result, the cross track magnetic anisotropy may be improved and domain lockup issues mitigated. Thus, performance of the disk drive **100** may be improved.

FIGS. **6**A, **6**B, **6**C, **6**D and **6**E depict ABS, first pole tip, second pole tip, yoke and side views, respectively, of a transducer **120'''** analogous to the transducers **120/120'/120"** and disk drive **100**. For clarity, FIGS. **6**A-**6**E are not to scale. For simplicity not all portions of the transducer **120'''** are shown. Because the magnetic recording transducer **120'''** is analogous to the transducers **120/120'/120"** in the magnetic disk drive **100**, analogous components have similar labels.

The transducer **120'''** includes a main pole **130'''** having sidewalls **136'''** and **138'''** that are analogous to the main pole **130/130'/130"** and sidewalls **136/136'/136"** and **138/138'/138"**, respectively. The main pole **130'''** also includes a pole tip region **132'''** and a yoke region **134'''** that are analogous to the pole tip **132/132'/132"** and yoke **134/134'/134"**, respectively. The pole tip region **132'''** is shown as having top and bottom bevels **131** and **133**, respectively, that are analogous to the bevels **131** and **133** depicted in FIGS. **2**, **3**C, **4**C and **5**C. The sidewalls **136'''** and **138'''** are configured such that the pole **130'''** has a bottom and a top wider than the bottom.

The sidewalls **136'''** and **138'''** form sidewall angles $\alpha0'''$ and $\alpha1'''$ with respect to the down track direction at the ABS and x1''', respectively. In addition, the sidewalls **136'''** and **138'''** form sidewall angles $\alpha2'$ and $\alpha3'$ at positions x2' and x3'. In the embodiment shown, $\alpha2'$ and $\alpha3'$ are substantially equal to $\alpha0'''$. Thus, the sidewall angle is substantially constant from the ABS to x2 and at least x3. In some embodiments, $\alpha0'''$ has a size range analogous to $\alpha0$. For example, $\alpha0'''$ may be at least twelve degrees and not more than fourteen degrees and in some embodiments may be nominally 13.5°. The sidewall angle $\alpha1'''$ is less than $\alpha0'''$ at x1'''. In the embodiment shown, $\alpha1'''$ is zero degrees. The distance x1''' may vary in a manner analogous to x1/x1'/x1". In some embodiments, x1''' is desired to be not more than the distance which the bevel **131** or **133** extends into the ABS. For example, in some embodiments, x1''' is not more than two hundred nanometers. In some embodiments, x1''' is desired to be closer to the ABS as described above. In general, x1''' is desired to be sufficiently large that the sidewall angle $\alpha O'''$ at the ABS remains unchanged. The manner in which the sidewall angle changes from $\alpha0'''$ to $\alpha1'''$ may vary. In some embodiments, the sidewall angle may change in a step function from $\alpha0'''$ to $\alpha1'''$ at some location after x3' and by x1'''. However, other configurations are possible. Although the variation in sidewall angle is described herein in terms of step function(s) and other mathematical functions, one of ordinary skill in the art will recognize that there exist processing and/or other limitations or considerations. Therefore, the transitions of such a "step" function may be rounded and/or transitions may not be sharp. Similarly, "linear" regions may not be perfectly straight. Thus, the actual profile of the main poles may not precisely follow the mathematical functions used herein.

The magnetic transducer **120'''** may exhibit improved performance for analogous reasons to those discussed above. Because of the variations in the sidewall angle, the magnetic field generated by the main pole **130'''** may be increased. The reverse overwrite gain may also be improved. The gradient in the magnetic field may also be improved while maintaining substantially the same side fields. As a result, adjacent track interference may not be adversely affected. Further, the pole tip region **132'''** of the main pole **130'''** may have an increased magnetic volume. As a result, the cross track magnetic anisotropy may be improved and domain lockup issues mitigated. Thus, performance of the disk drive **100** may be improved.

FIG. **7** depicts an exemplary embodiment of a method **300** for providing a magnetic recording transducer **120** having a main pole that may has a varying sidewall angle, such as main pole **130**, **130'**, **130"**, and/or **130'''**. For simplicity, some steps may be omitted, interleaved, and/or combined. The method **200** is also described in the context of providing a magnetic recording head **100** and transducer **120** depicted in FIGS. **2**, **3**A, **3**B and **3**C. However, the method **200** may be used to fabricate multiple magnetic recording heads at substantially the same time. The method **200** may also be used to fabricate other magnetic recording transducers including but not limited to any combination of **120**, **120'**, **120"**, and/or **120'''**. The method **200** is also described in the context of particular layers. A particular layer may include multiple materials and/or multiple sub-layers. The method **200** also may start after formation of other portions of the magnetic recording head. For example, the method **200** may start after a read transducer, return pole/shield and/or other structure have been fabricated.

Referring to FIGS. **2**, **3**A-**3**C and **7**, the main pole **130** is provided, via step **202**. Step **202** may include using one or more damascene processes. For example, a trench may be formed in a layer. The trench may be fabricated such that portions of the trench sidewalls form different angles with the down track direction. The material(s) for the pole **130** deposited, for example via plating. One or more ferromagnetic materials may be used. The pole tip **132** and yoke **134** may be formed. Other methods may also be used to form the pole **130** including but not limited to full film deposition of magnetic materials and removal for example via milling and/or lapping.

The coil(s) **140** are provided, via step **204**. Portions of step **204** may thus be interleaved with the remaining steps of the method **200**. For example, portions of the coil **140** may be provided before the formation of the main pole **130**. However, other portions of the coil **140** may be provided after some or all of the main pole **130** has been formed. Step **204** may also include depositing and patterning the material(s) used for the coil(s) **140**. Step **204** may include forming a single helical coil or one or more pancake/spiral coil. In such embodiments, a pancake coil **140** may include other turns far from the ABS.

Using the method **200**, the magnetic disk drive **100** and magnetic transducers **120**, **120'**, **120"** and/or **120'"** may be provided. Thus, the benefits of the magnetic transducers **120**, **120'**, **120"** and/or **120'"** may be achieved.

FIG. **8** depicts an exemplary embodiment of a method **210** for providing a magnetic recording transducer **120** having a main pole that may has a varying sidewall angle, such as main pole **130**, **130'**, **130"**, and/or **130'"**. For simplicity, some steps may be omitted, interleaved, and/or combined. The method **210** is also described in the context of providing a magnetic recording head **100** and transducer **120** depicted in FIGS. **2**, **3**A, **3**B and **3**C. However, the method **210** may be used to fabricate multiple magnetic recording heads at substantially the same time. The method **210** may also be used to fabricate other magnetic recording transducers including but not limited to any combination of **120**, **120'**, **120"**, and/or **120'"**. The method **210** is also described in the context of particular layers. A particular layer may include multiple materials and/or multiple sub-layers. The method **210** also may start after formation of other portions of the magnetic recording head. For example, the method **210** may start after a read transducer, return pole/shield and/or other structure have been fabricated.

Referring to FIGS. **2**, **3**A-**3**C and **8**, materials are provided in layers that are perpendicular to the ABS, via step **212**. For example, one material may extend from the ABS to **x1**, while another extends from **x1** to further from the ABS. In other embodiments, such as the transducer **120"**, one material may extend from the ABS to **x2**, another from **x2** to **x3**, a third from **x3** to **x1** and a fourth from **x1** to further from the ABS.

A trench is etched for the pole, via step **204**. Step **204** may include using one or more damascene processes. The different materials may have different etch characteristics. Consequently, each material may etch a different amount and provide a portion of the trench that has a different profile. Thus, the trench may have different sidewall angles at different distances from the ABS. The material(s) for the pole **130** deposited, via step **216**. One or more ferromagnetic materials may be plated. The pole tip **132** and yoke **134** may be formed.

Using the method **210**, the main pole **130**/**130'**/**130"**/**130'"**, magnetic disk drive **100** and magnetic transducers **120**, **120'**, **120"** and/or **120'"** may be provided. Thus, the benefits of the magnetic transducers **120**, **120'**, **120"** and/or **120'"** may be achieved.

We claim:

1. A magnetic transducer having air-bearing surface (ABS) comprising:

a main pole including a pole tip region and a yoke region, the pole tip region including a plurality of sidewalls, a bottom surface, and a top surface wider than the bottom surface, the plurality of sidewalls being between the top surface and the bottom surface, the top surface being opposite to the bottom surface and in a down track direction from the bottom surface, at least one of the plurality of sidewalls forming a first sidewall angle with a down track direction at the ABS and a second sidewall angle with the down track direction at a first distance recessed from the ABS in a yoke direction perpendicular to the ABS, the first sidewall angle being greater than the second sidewall angle, the down track direction being parallel to the ABS and perpendicular to the yoke direction, the first sidewall angle and the second sidewall angle being formed by the at least one of the plurality of sidewalls at the bottom surface of the main pole; and

at least one coil for energizing the main pole.

2. The magnetic transducer of claim **1** wherein the second sidewall angle is zero degrees.

3. The magnetic transducer of claim **1** wherein the plurality of sidewalls form a third sidewall angle with the down track direction at a second distance recessed from the ABS, the second distance being less than the first distance and the third sidewall angle being greater than the second sidewall angle.

4. A magnetic transducer having air-bearing surface (ABS) comprising:

a main pole including a pole tip region and a yoke region, the pole tip region including a plurality of sidewalls, a bottom surface, and a top surface wider than the bottom surface, the plurality of sidewalls being between the top surface and the bottom surface, the top surface being opposite to the bottom surface and in a down track direction from the bottom surface, at least one of the plurality of sidewalls forming a first sidewall angle with a down track direction at the ABS and a second sidewall angle with the down track direction at a first distance recessed from the ABS in a yoke direction perpendicular to the ABS, the first sidewall angle being greater than the second sidewall angle, the down track direction being parallel to the ABS and perpendicular to the yoke direction, wherein the plurality of sidewalls form a third sidewall angle with the down track direction at a second distance recessed from the ABS, the second distance being less than the first distance and the third sidewall angle being greater than the second sidewall angle and wherein the plurality of sidewalls form a fourth sidewall angle with the down track direction at a third distance recessed from the ABS, the third distance being less than the first distance and the fourth sidewall angle being greater than the second sidewall angle; and

at least one coil for energizing the main pole.

5. The magnetic transducer of claim **1** wherein the plurality of sidewalls form the first sidewall angle between the ABS and the first distance.

6. The magnetic transducer of claim **1** wherein the plurality of sidewalls form a sidewall angle with the down track direction that substantially monotonically decreases between the first sidewall angle and the second sidewall angle.

7. The magnetic transducer of claim **1** wherein the plurality of sidewalls form a sidewall angle with the down track direction that substantially linearly decreases between the first sidewall angle and the second sidewall angle.

8. The magnetic transducer of claim **1** wherein the plurality of sidewalls form a sidewall angle with the down track direction that decreases between the first sidewall angle and the second sidewall angle in accordance with a piecewise linear manner.

9. The magnetic transducer of claim **1** wherein the plurality of sidewalls form a sidewall angle with the down track direction that decreases between the first sidewall angle and the second sidewall angle in accordance with at least one step function.

10. The magnetic transducer of claim **1** wherein the plurality of sidewalls form a sidewall angle with the down track direction that decreases between the first sidewall angle and the second sidewall angle in accordance with a function having a power greater than one.

11. The magnetic transducer of claim **1** wherein the first sidewall angle is at least eleven degrees and not more than fifteen degrees.

12. The magnetic transducer of claim **1** wherein the first distance is greater than zero and not more than two hundred nanometers.

13. The magnetic transducer of claim **12** wherein the first distance is at least ten nanometers and not more than one hundred nanometers.

14. The magnetic transducer of claim **12** wherein the first distance is at least thirty nanometers and not more than eighty nanometers.

15. The magnetic transducer of claim **1** wherein the main pole further includes a bevel extending a bevel distance from the ABS, the first distance being less than or equal to the bevel distance.

16. A disk drive comprising:

a magnetic recording medium,

a slider, and

a magnetic transducer coupled with the slider, the magnetic transducer having air-bearing surface (ABS), a main pole and at least one coil for energizing the main pole, the main pole including a pole tip region and a yoke region, the pole tip region including a plurality of sidewalls, a bottom surface, and a top surface wider than the bottom surface, the plurality of sidewalls being between the top surface and the bottom surface, the top surface being opposite to the bottom surface and in a down track direction from the bottom surface, the magnetic recording medium moving in the down track direction with respect to the magnetic transducer, at least one of the plurality of sidewalls forming a first sidewall angle with a down track direction at the ABS and a second sidewall angle with the down track direction at a first distance recessed from the ABS in a yoke direction perpendicular to the ABS, the first sidewall angle being greater than the second sidewall angle, the down track direction being parallel to the ABS and perpendicular to the yoke direction, the first sidewall angle and the second sidewall angle being formed by the at least one of the plurality of sidewalls at the bottom surface of the main pole.

17. A method for fabricating magnetic transducer having air-bearing surface (ABS) comprising:

providing a main pole including a pole tip region and a yoke region, the pole tip region including a plurality of sidewalls, a bottom surface, and a top surface wider than the bottom surface, the plurality of sidewalls being between the top surface and the bottom surface, the top surface being opposite to the bottom surface and in a down track direction from the bottom surface, at least one of the plurality of sidewalls forming a first sidewall angle with a down track direction at the ABS and a second sidewall angle with the down track direction at a first distance recessed from the ABS in a yoke direction perpendicular to the ABS, the first sidewall angle being greater than the second sidewall angle, the down track direction being parallel to the ABS and perpendicular to the yoke direction, the first sidewall angle and the second sidewall angle being formed by the at least one of the plurality of sidewalls at the bottom surface of the main pole; and

providing at least one coil for energizing the main pole.

18. The method of claim **17** wherein the second sidewall angle is zero degrees.

19. The method of claim **17** wherein the step of providing the main pole further includes:

configuring the plurality of sidewalls to form a third sidewall angle with the down track direction at a second distance recessed from the ABS, the second distance being less than the first distance and the third sidewall angle being greater than the second sidewall angle.

20. A method for fabricating magnetic transducer having air-bearing surface (ABS) comprising:

providing a main pole including a pole tip region and a yoke region, the pole tip region including a plurality of sidewalls, a bottom surface, and a to surface wider than the bottom surface, the plurality of sidewalls being between the to surface and the bottom surface, the top surface being opposite to the bottom surface and in a down track direction from the bottom surface, at least one of the plurality of sidewalls forming a first sidewall angle with a down track direction at the ABS and a second sidewall angle with the down track direction at a first distance recessed from the ABS in a yoke direction perpendicular to the ABS, the first sidewall angle being greater than the second sidewall angle, the down track direction being parallel to the ABS and perpendicular to the yoke direction wherein the step of providing the main pole further includes

configuring the plurality of sidewalls to form a third sidewall angle with the down track direction at a second distance recessed from the ABS, the second distance being less than the first distance and the third sidewall angle being greater than the second sidewall angle; and

configuring plurality of sidewalls to form a fourth sidewall angle with the down track direction at a third distance recessed from the ABS, the third distance being less than the first distance and the fourth sidewall angle being greater than the second sidewall angle; and

providing at least one coil for energizing the main pole.

21. The method of claim **17** wherein the plurality of sidewalls form the first sidewall angle between the ABS and the first distance.

22. The method of claim **17** wherein the step of providing the main pole further includes:

configuring the plurality of sidewalls to form a sidewall angle with the down track direction that substantially monotonically decreases between the first sidewall angle and the second sidewall angle.

23. The method of claim **17** wherein the step of providing the main pole further includes:

configuring the plurality of sidewalls to form a sidewall angle with the down track direction that substantially linearly decreases between the first sidewall angle and the second sidewall angle.

24. The method of claim 17 wherein the step of providing the main pole further includes:

configuring the plurality of sidewalls form a sidewall angle with the down track direction that decreases between the first sidewall angle and the second sidewall angle in accordance with a piecewise linear manner.

25. The method of claim 17 wherein the step of providing the main pole further includes:

configuring the plurality of sidewalls form a sidewall angle with the down track direction that decreases between the first sidewall angle and the second sidewall angle in accordance with at least one step function.

26. The method of claim 17 wherein the step of providing the main pole further includes:

configuring the plurality of sidewalls form a sidewall angle with the down track direction that decreases between the first sidewall angle and the second sidewall angle in accordance with a function having a power greater than one.

27. The method of claim 17 wherein the step of providing the main pole further includes:

providing a plurality of layers in a direction substantially perpendicular to the ABS, the plurality of materials having a plurality of removal characteristics;

removing a portion of each of the plurality of layers to form a pole trench in the plurality of layers, the pole trench having a location and a profile corresponding to the main pole; and

providing at least one pole material in the pole trench.

28. The method of claim 17 wherein the main pole further includes a bevel extending a bevel distance from the ABS, the first distance being less than or equal to the bevel distance.

* * * * *